POWER WITHOUT THE GRID: A SELF-CONTAINED RENEWABLE ENERGY STATION

A CREATIVE PROJECT

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

MASTER OF ARTS

BY

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Stan Penner, a career electronics repairman in Northwest Indiana's Steel mills, who without his insight, suggestions, and tools, this project never would have been completed.

Table of Contents

Abstract

Power without the Grid: A Self-Contained Renewable Energy Station

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PAGES: 43

The reported project involves the development of an outdoor solar-powered station which would allow local citizens to use electrical energy generated from the sun, stored in batteries, free of charge. This renewable energy station is designed for use in a public space. The site selected for this prototype is the former Car Doctors site, Muncie, IN, which is being converted to a community green space. The system includes a solar panel which is run through a charge controller to a battery. The charge controller is an inline device that prevents overcharging the battery. The battery is stored in a water-tight container. A pico-grid scale system was ultimately created that is free from the local electrical grid but small enough that it can be placed nearly anywhere to provide electrical access. This presented practical problems that needed to be managed to ensure sufficient charge, battery capacity, weatherproofing, and theft-resistance as well as adhering to applicable municipal codes. Due to the modular nature of the design the station can be placed in more convenient locations than a traditional electrical outlet. This renewable energy system provides a valuable amenity for a public space. Increased amenities, and increased utility, may lead to increased usage of parks and other public spaces. The solar station shows how solar technology can be applied to the individual scale; furthermore, it demonstrates some of the common-sense ways that we can 'green' our lives using simple modular electrical systems.

Introduction

GSMA is an international organization that provides services and sets standards for the mobile device industry worldwide. According to their calculations, there are about 8.4 billion mobile devices worldwide.[i] According to the latest estimates from the United States Census Department there are approximately 7.4 billion people in the world, meaning there are more devices than there are people.[ii] One issue common to all mobile devices is loss of power. The majority of mobile devices are able to be charged using the Universal Serial Bus, better known by its initials 'USB.' The current project poses the question: Can we create a way to provide additional charging locations, especially in non-traditional areas such as parks or recreational areas, and be able to positively impact the individuals using those spaces while also harnessing green technology?

The Car Doctors site is a brownfield site in Muncie that is currently being rehabilitated with the intention of transforming it into a usable green space for the community. The site measures about five acres in size and is located on the north side of Burlington Drive in the Blaine neighborhood. It had previously been used as an automotive scrapyard before being abandoned for several years. It was later used as a convenient waste dump.

Review of Literature

One of the challenges of the current project is the scarcity of specific scholarly writings on the topic of USBs for remote locations. Jangjoo and Seifi (2014) address many applications and complications with mobile device load on a microgrid.[iii] The current system, as with the nano-grid scale work of Schonberger et al. (2006), uses DC current because "dc offers advantages such as improved transmission efficiency and ease of interfacing asynchronous sources such as wind turbines to the system," even though only a single source is needed to interface into our system.[iv] This system against the suggestions of Schonberger et al. (2006), does include a central controller, something those authors deemed a weakness in reliability because all of the parts of the system were dependent upon that central controller, and if it failed the system as a whole will fail.[v] Their work on DC-Bus Signaling and the ability to balance between several different sources and prioritizing is beyond the scope of this project but will be an integral part of any sort of smart grid system.

In their work about energy storage and uninterrupted power, Ghai et al. (2013) used the phrase "DC picogrid" to characterize miniaturized smart grid with a battery charging unit from the grid that steps in to power a DC appliance.[vi] A DC picogrid is probably the closest term to this system built for the current project. This system uses a solar panel to provide energy instead of being charged from a larger grid or other outside source, such as what is described in Ghai et al. (2013).[vii] Those authors have also decided to that operating entirely as DC is more efficient than converting between AC and DC. This was a consideration early in the project and the ability to have a Type A two-pronged socket or the Type B three-pronged 110 V outlet would have greatly increased the utility of this project. The 20-25% losses cited by Ghai et al.

(2013) in the conversation from DC to AC power seemed excessive for such a small system; therefore, the more efficient, entirely DC system, was used instead.[viii]

Tan et al. (2016) discuss the practice of having an inner control loop and an outer generation loop within smart microgrid systems.[ix] This is carried out so that the controller will be aware as generation rises and falls or is cut out entirely, so that it can then bring another source onto that smart grid, whether it be the main grid, an additional renewable source, or an energy storage source to help supplement demand. This system has a similar central controller and is not designed to provide direct charging from the solar panel to the load. Rather, the solar panel can only charge the batteries and then the batteries provide power to the USB load but the central charge controller operates in a similar if smaller scale.

In the Marnay et al. (2012) characterizations, instead of ever-decreasing-sized grids being labeled with ever decreasing units, such as nano- and pico-, he sees a jump and instead refers to networks powered by Cat-5 ethernet cables to be nano-grids.[x] The use of Cat-5 cable as a choice of wiring for this project was recommended by one wiring expert at a Home Improvement store. It was suggested that Cat-5 cables are already pre-color-coded and could support relatively low voltages, similar to the reasons that Marnay et al. (2012) characterizes as a viable option for nano-grids. Ball State University began using such grids in the Spring of 2017 with Ethernet-powered telephone systems. While these systems should be differentiated from traditional grids, nano-grid may not actually be a correct term. Some of these systems, such as Ball State's Ethernet-charged system, span the entire campus and may potentially connect hundreds of telephones plus many more computers.

With the massive growth in use and decrease in cost, solar panels are becoming increasingly more common in everyday applications. Popovich (2017) states that there are more than twice as many solar jobs in the United States as there are coal jobs, a traditional energy staple.[xi] The solar industry promises, also, plenty of future growth. There are several different forms of solar energy. For this paper only photovoltaic (PV) systems are addressed. However, for larger, industrial-scale applications there are solar options using molten salt or concentrated solar that generate electricity due to the heat of the sun rather than by using photons.

The reported system was carried out with a polycrystalline panel, something noted in Kerns (2017) as being the least efficient type of photovoltaic panel. It also tends to be the least expensive option and is only about 2% less efficient then the slightly more expensive monocrystalline panels.[xii] The scale of the currents project means that such a small difference should not have a substantial impact and the 6-watt panel should prove sufficient given the amount of foot traffic and the amount of sunlight in the area. Future variations on this plan have suggested the possibility of including expandable sunshades. If Kerns (2017) is correct and Thin-Film variations continue to decrease in price, it may become viable to use those expandable sunshades to increase energy generation during time periods of high demand.[xiii]

The Project

This project was initiated by an individual with limited knowledge of electrical systems and construction practices but with an interest in renewable energy systems and an idea on how we may be able to make them more accessible to the general public, at least on a small scale. This project has involved learning basic circuits and wiring, the properties of different solar panels and what they may be used for, and angles for the optimum generation. I needed to learn about civic requirements and building practices while also learning the hands-on construction skills to physically bring the project together. As much time was spent reviewing scholarly articles as was spent reading DIY materials and combing through City Ordinances.

A solar panel, attached to some batteries in a field is not something that has an immediately obvious utility. The system is too small to power a house or make any sort of impact on the grid had it been connected, so why it is there?

Mobile devices have become an integral part of modern life. This implies that the limitations of their batteries and the necessity to recharge them has become an integral part of life. This is a repeatable set-up that could be managed with very little infrastructure in public spaces.

The solar charger is a concept that could be made modular easily enough to be used to provide energy and help with communications in areas without access to electricity. An example of getting a phone or device to charge is the recent hurricane season that has left much of the island of Puerto Rico without power and with many citizens struggling to communicate with the outside world. A mobile charge system can be paired with Google's Project Loon, a balloon-based mobile WiFi connection that allows internet and telephone connection to areas without infrastructure.[xiv] Creating systems for using solar energy, storing it and then being able to access it, away from the grid, has a compelling place in the future.

Materials and Methods

Finding a sufficient battery supply that would allow for charge and discharge without creating a hazardous environment for the other electronics stored with it or any individuals that may have to service it was an early decision. Two 6-V Lithonia™ Lighting sealed rechargeable batteries were chosen and used in series to provide the needed 12V for this system. These batteries, normally used in emergency lights in buildings, were chosen because of their sealed configuration. This addressed worries that wet batteries may create toxic environments if confined, as well as the fact that they typically have expected lifespans of 5+ years, meaning that they should work for many years with little to no maintenance. With 10 amp hour storage capacity they should be able to endure a night or even several days of no sun and still be able to contain sufficient energy to recharge many devices. In testing using a Fluke™ 787 processmeter a parasitic loss of energy of 4mA in the charging device was noted. In other words, with no devices attached to the system the USB charger drew 4 mA, meaning if the batteries were not charged and the USB hookup was unused, it would take 104 days for the USB plug to deplete the 10Ah batteries. This was agreed to be plenty of capacity within a reasonably-sized unit.

The Charge Controller is a Renogy™ Adventurer 12v charge controller. This unit is wired between the solar panel and the batteries. This unit balances the batteries, ensuring that they do not get overcharged and destroy the batteries. This model was chosen because it has a negative ground capability. In discussing this project with the Muncie Electrical inspector, the importance of ensuring that it is properly grounded was emphasized. This charger will allow a ground wire to be run out of the negative charge terminal, making an easier installation and complying with Muncie Indiana Civic Code.

The solar panel is a 6-watt, 12-volt Weatherproof Coleman™ Solar Panel. It is designed with the intention of trickle charging batteries for RVs and may therefore be placed outdoors. It will slowly provide charge so that when camping season comes around next year the battery in the vehicle will be charged. This should work well for the reported application where this system will also be left outside exposed to the elements. The outer case is weather- and shock-proof, thus increasing durability.

Electrical PVC was chosen for the tubing. This will encase the more sensitive electronics and will cover the electrical wires running to and from various components. The possible alternative would have been a galvanized metal conduit. PVC was chosen as it is easier to cut and shorten to the required length and because of the additional ability to be an insulator. Metal conduits would, in contrast, act as a conductor. The electrical-specific PVC is designed to be UV-resistant, an important feature when used with a solar panel, which must be sited in full sunlight to maximize its effectiveness.

The original plans for this project had the control box being buried, removing it from sight and making the batteries and electronics more resistant to theft as well as removing it from view. The plan was altered, with the box being placed low on the post to remove it from sight but to allow access for any maintenance or updating of materials. Additionally, burying the box left the difficult choice of encasing it in the cement foundation or having it marginally attached and placed several feet from the post. While such positioning would have aided in limiting theft, it would have also increased the difficulty of servicing and the likelihood that, if near the surface, it could be hit by equipment like a lawnmower.

Construction

A wooden 4’’ x 4’’ treated wood post was used as the main structural element for this design. The post is 12’ tall, with about 3’ of that length in the ground, cemented in to provide a firm foundation. The alternative would have been a metal fence post which would have proven smaller and more compact. The wooden post was chosen because it was easier to fasten items to as well as being easier to cut in size as needed; finally, it offered some area for painting or decorative design if someone were to use this and provide their own personal touch, something that would have been much more limited on a metallic fence post.

Originally a box had been selected with a 8”x8”x4” size, pictured in Figure 1. All of the components fit within, but only with very close quarters that would have made wiring very difficult and may have created issues due to heat generation.

Figure 1. Electrical box.

The larger 12”x12”x 6” box had a problem of being difficult to place directly on the post, but for the purposes of wiring and constructing the project, it was a positive change. The larger box also provides space for potential future additions such as an inverter which would allow this or a similar project to use a 110V Type A or Type B socket instead of the 12V USB-based plug. The larger box also allows for increasing the size and capacity of the batteries used in future applications.

Three water-tight holes were placed in the box. The first hole allowed the wires from the solar panel to enter the box. The second hole, in the back of the box, was used to run up to the receptacle with the USB plug. The final hole, in the bottom of the box, is for the grounding wire to be run to the grounding rod in the soil. A key point with these is that each time we put a new hole in the box we introduce a new route for water to potentially enter, so care was taken to ensure that all fittings were tight, and after placement were cemented in place using a PVC adhesive to create an additional water barrier.

Figure 2. Box with visible holes drilled in the top, back, and bottom.

The box was mounted onto the post, placed about 6 inches above ground level. At this point it was possible to determine the location for the USB housing, mount it, and run the PVC piping to its location. The USB housing was targeted as being about 42 inches above ground level to maintain compliance with the Americans with Disabilities Act which requires that plugs and switches be no more than 48 inches above the ground.[xv] This height may vary slightly depending on the depth of the hole ended and how well the concrete cured beneath the post, which is why a 6” margin for error was used.

Figure 3. PVC attachment to post.

Three-quarter-inch PVC pipe and associated pipe straps were used during installation. The straps were placed along the run of PVC to secure it to the center post. Two pipe straps were selected and used with 2” decking screws. These screws should provide very firm attachment to the post while also resisting rust for many years.

In Fig. 3, housing for the USB port is already on the post but not completely assembled. The weatherproof cover has not been attached. It was essential to first fit all of the components, finalize their locations and then drill or adhere them to their desired location. At this point it was possible to run wires between the USB housing to the box.

At the top of the post the solar panel is screwed into a second piece of treated lumber and mounted at a 40-degree angle. The published literature provides many suggestions on the optimum angle for a solar panel. Chua and Yong (2017) tested between 30 and 40 degrees and recommended the 40-degree angle as the best fixed angle; however, due to different locations relative to latitude and time of year, that angle can change.[xvi] Several solar-centric websites suggested to take your latitude and add 15 degrees during winter, making the panel more vertically angled south. During summer, the user is to change the angle, subtracting the original 15 degrees and an additional 15 degrees, angling the panel more horizontally to increase collection of the more directly overhead sun.[xvii] Since we are using a fixed angle it was important to find a suitable fit for year-round generation. The 40-degree angle for our panel is corroborated by the Yaw and Yoon study (2017) as well as almost exactly Muncie's latitude.[xviii]

After securing the panel mount to the post the wires were run from the panel down into the control box. The wires were not attached to the charge controller at this point because of concerns about damage during transit. Final assembly and wiring was completed at the former Car Doctor's site after the post had been cemented into the ground.

Because of its history as a scrapyard the ground at the site is extremely hard. I was informed that there is a layer of compacted gravel about one foot below ground level that had resisted previous attempts to install fence posts. With this information I rented a hydraulic gasoline-powered post hole auger.[xix] This was strong enough to break through the layer of compacted gravel. The post hole reached about 3 feet deep, the 30 inches I had been told was the minimum requirement for Muncie Civic code by the Muncie City Electrical Inspector with about 6 inches extra for additional strength.[xx]

The general area of the dig site was marked in white paint (Fig. 4). The utility locator then wrote "OK" in blue paint after clearing the area and surveying.

Figure 4. Base of the pole, Car Doctors site.

The white circle as well as the blue paint and blue flag were placed to signify that it was safe to dig in this area. It is essential to call 811 before digging, as the potential liability and hazards of inadvertently hitting a buried electrical cable or underground gas line are great.

The post was secured in an 8”-wide borehole with three 50-lb. bags of quick-hardening cement. The post is oriented south and slightly to the west. This was done for two reasons; first, the slight western orientation provides greater afternoon energy generation (which is the time of day that this system would, hopefully, be used most). The second reason is that the closest tall vegetation to the system is to the south and east. While this vegetation is not currently tall enough to shade the panel, favoring the west may provide, over the long term, more direct sunlight.

After allowing the concrete to cure overnight the electrical components were wired and the system checked to ensure that it functioned as designed. Figure 5 shows the two wires that lead to the USB housing being held to the battery terminals to ensure that the connections were still intact and that the USB housing did in fact charge.


Figure 5. Checking the electrical system.

The two color-coded wires were run down from the USB hub and were checked before wiring them into the charge controller. There are two 1.5-A fuses in this system as well -- one on the wiring running to the USB hub and one in the wiring running to the batteries. Two wires were then run from the charge controller to the batteries while a third set of wires came from the solar panel into the charge controller.

The photo in Figure 6 was taken before closing the box up but after all of the final wiring had been completed. It shows the various wiring, the two visible inline fuses and the charge controller with power flowing to it. At the moment of this photo the charge controller indicated that the batteries were being charged from the solar panel and that the air temperature registered at 27° C or about 80°F. This number was artificially inflated by the black box of the sensor in full sunlight; installation was completed on a November day that had a high of 52° F.

Figure 6. Testing the components.

Figure 7

Figure 7 shows the system in use. The USB wire runs from the USB plug to the device that was used to take the photo. The system was working as intended and the device was able to gain energy powered entirely from the sun.

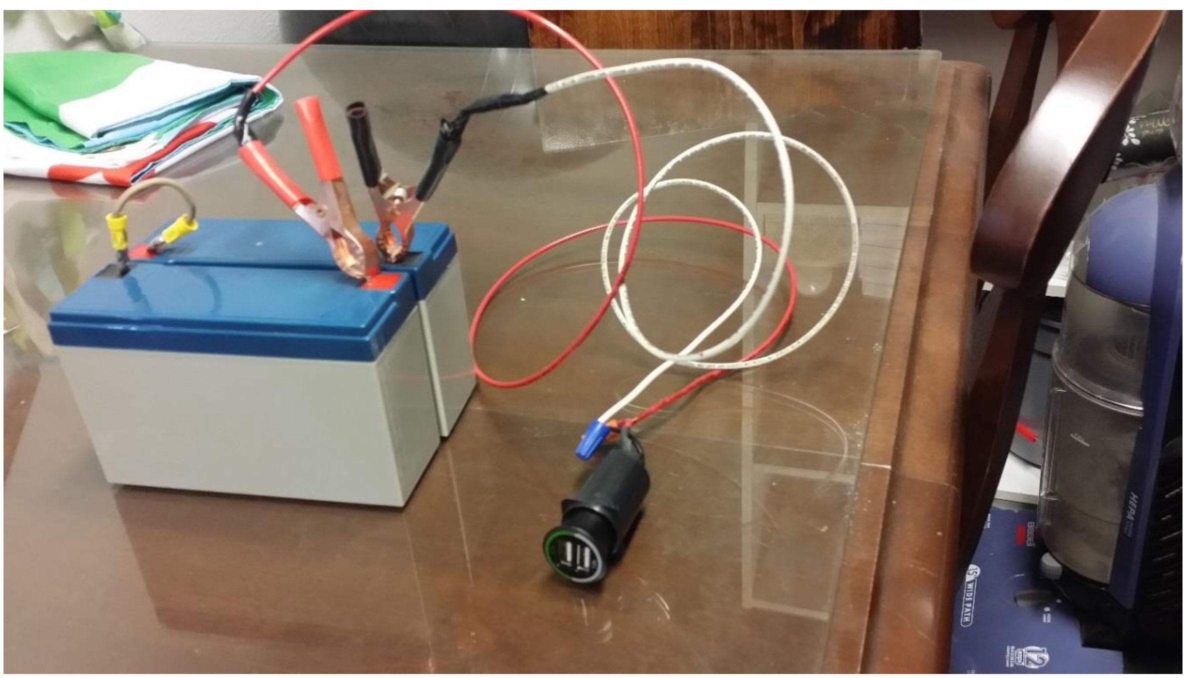
Some work still needs to be completed, and that by a licensed professional. I am awaiting word from the International Brotherhood of Electrical Workers that the system has been successfully grounded and that the electrical permit for the city has been completed. Grounding provides a route to safely disperse built-up excess energy, in this case safely to the earth in the form of a steel and copper rod that is driven several feet into the soil. In the case of electrical build-up or a lightning strike, this offers a safe way to disperse the electrical energy.

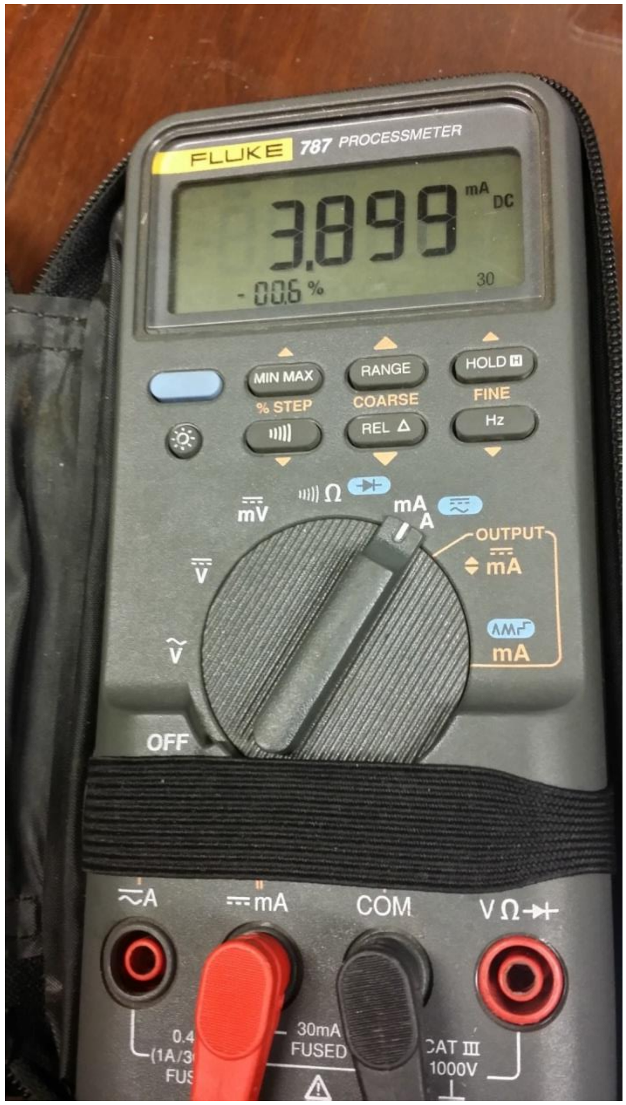
Appendix

Photographs of the Solar Project

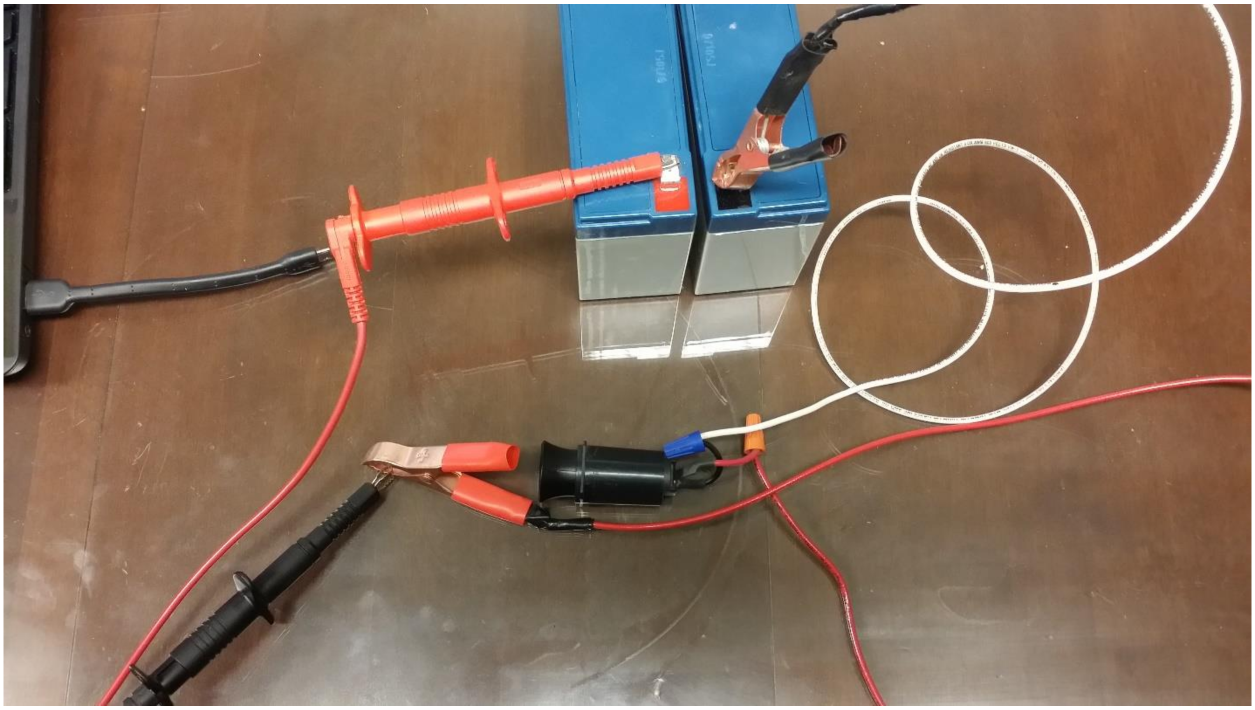
Above: Both batteries wired-up in series

Below: Batteries wired to USB outlet to verify wiring was connected correctly.





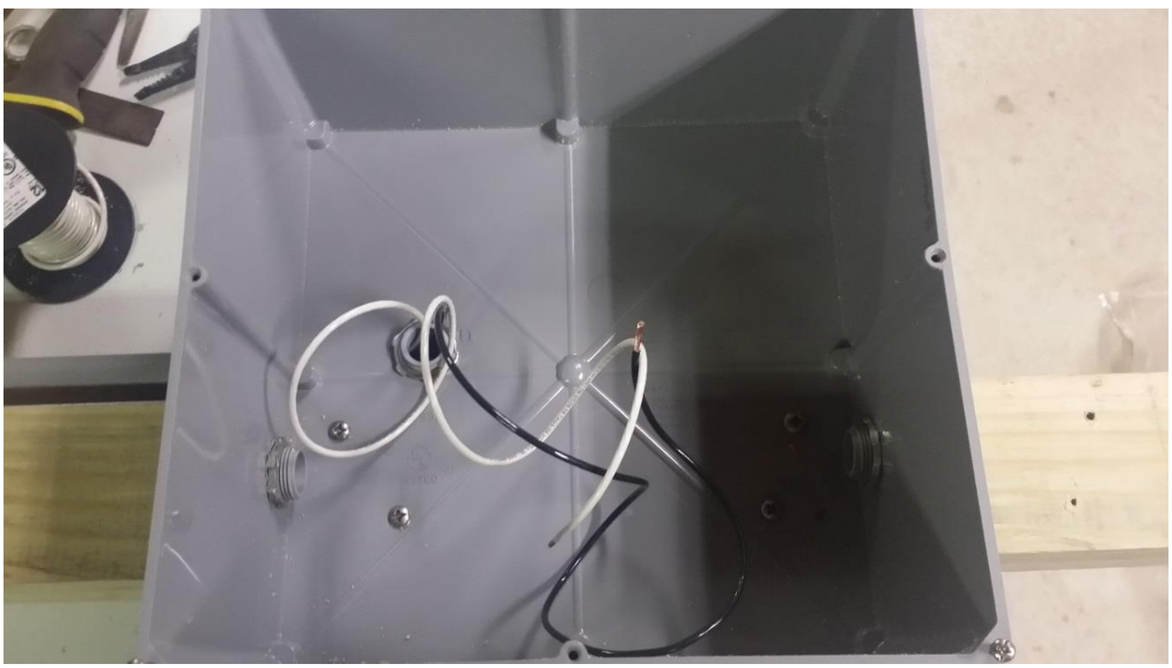
Fluke 787 Process meter showing the nearly 4 mA draw that the USB port drew with no additional load.



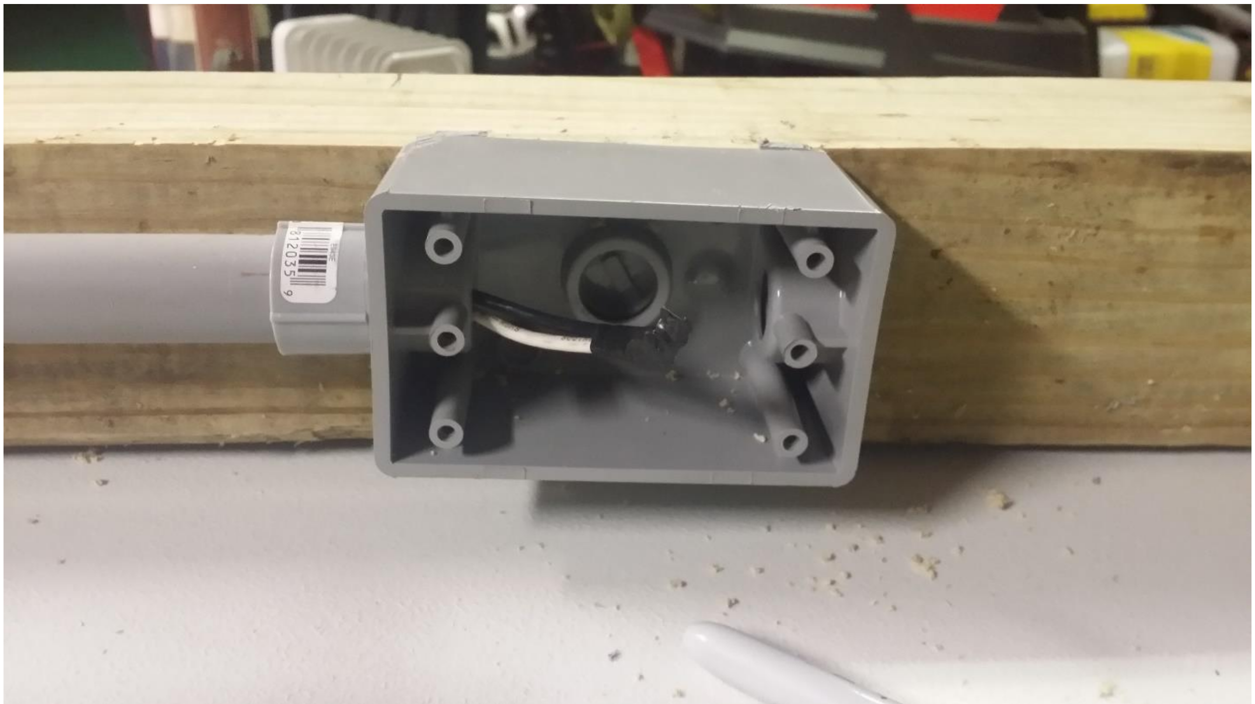
The wiring connections that generated the 4mA reading from the previous photo.

Area labeled for 811 site survey.

Main control box before being fastened to the main post.

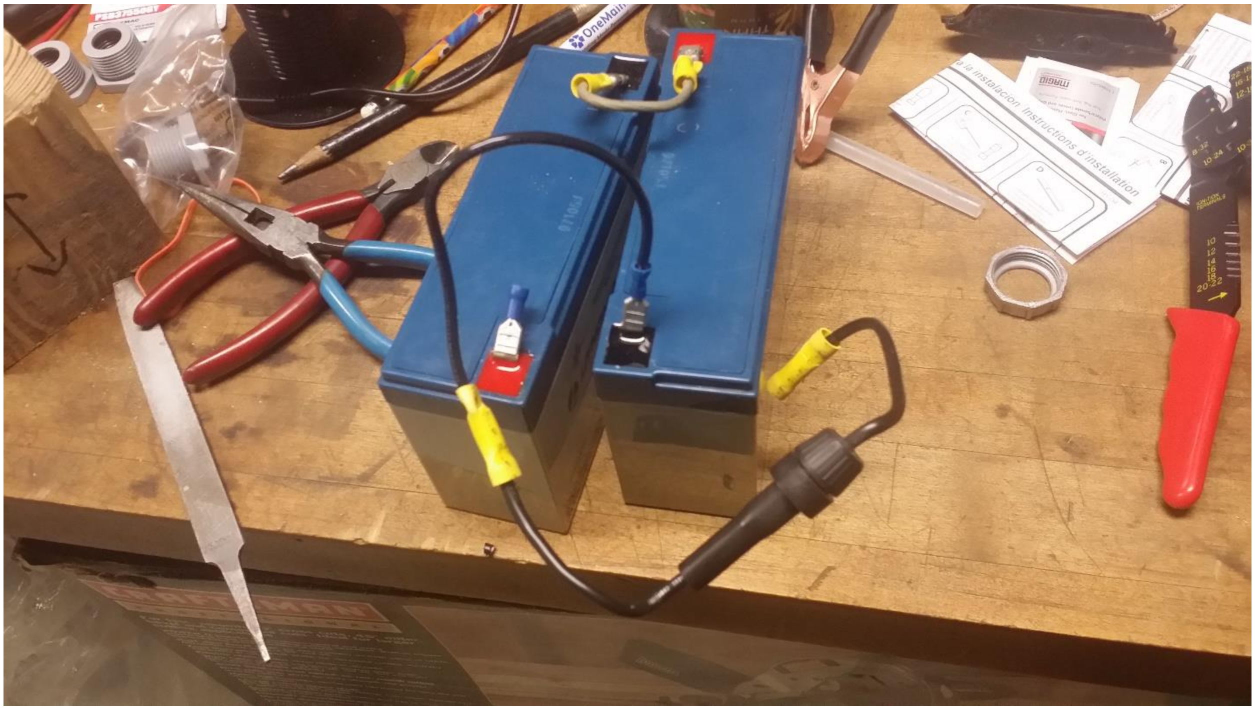


Main control box with first wiring run. Positive and negative wires from USB outlet. The box has been secured to the post.



Wiring run to 1 gang box that would become USB housing.

Main control box with solar panel and USB wiring run.



Batteries with inline fuse attached, visible on either side of the fuse.

USB one gang outlet with weatherproof covering.

Blue verification paint from 811 surveyor at the dig site.

Post in hole, lower extension and reinforcing bracket attached.

Post now in hole about 36 inches deep, while concrete is setting.


ENARDS
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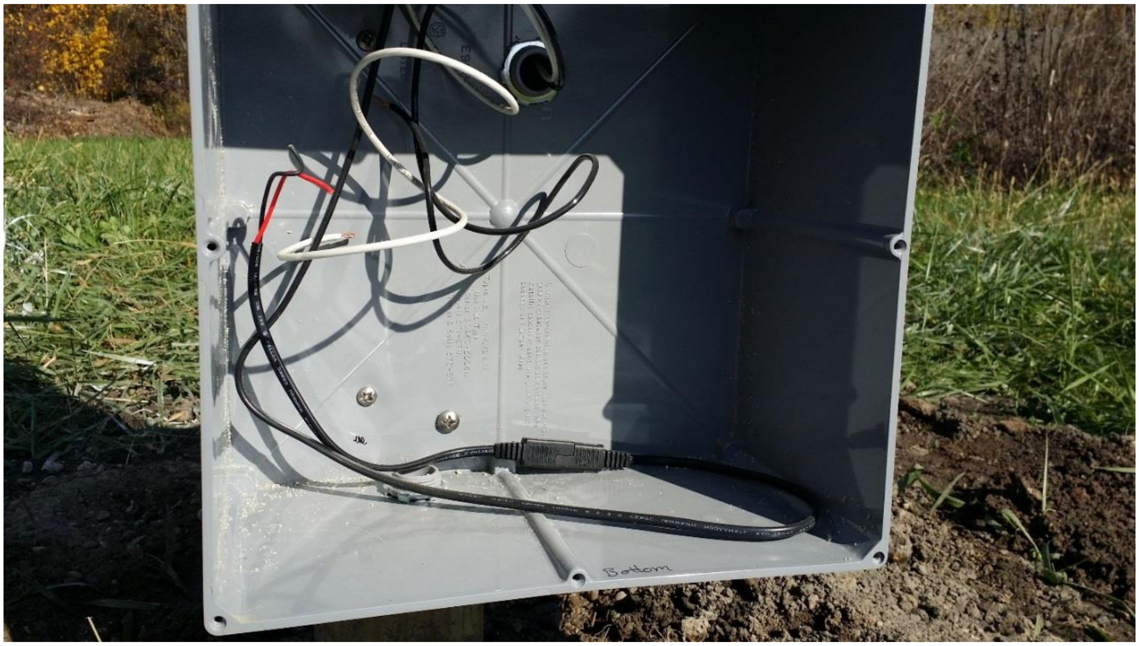
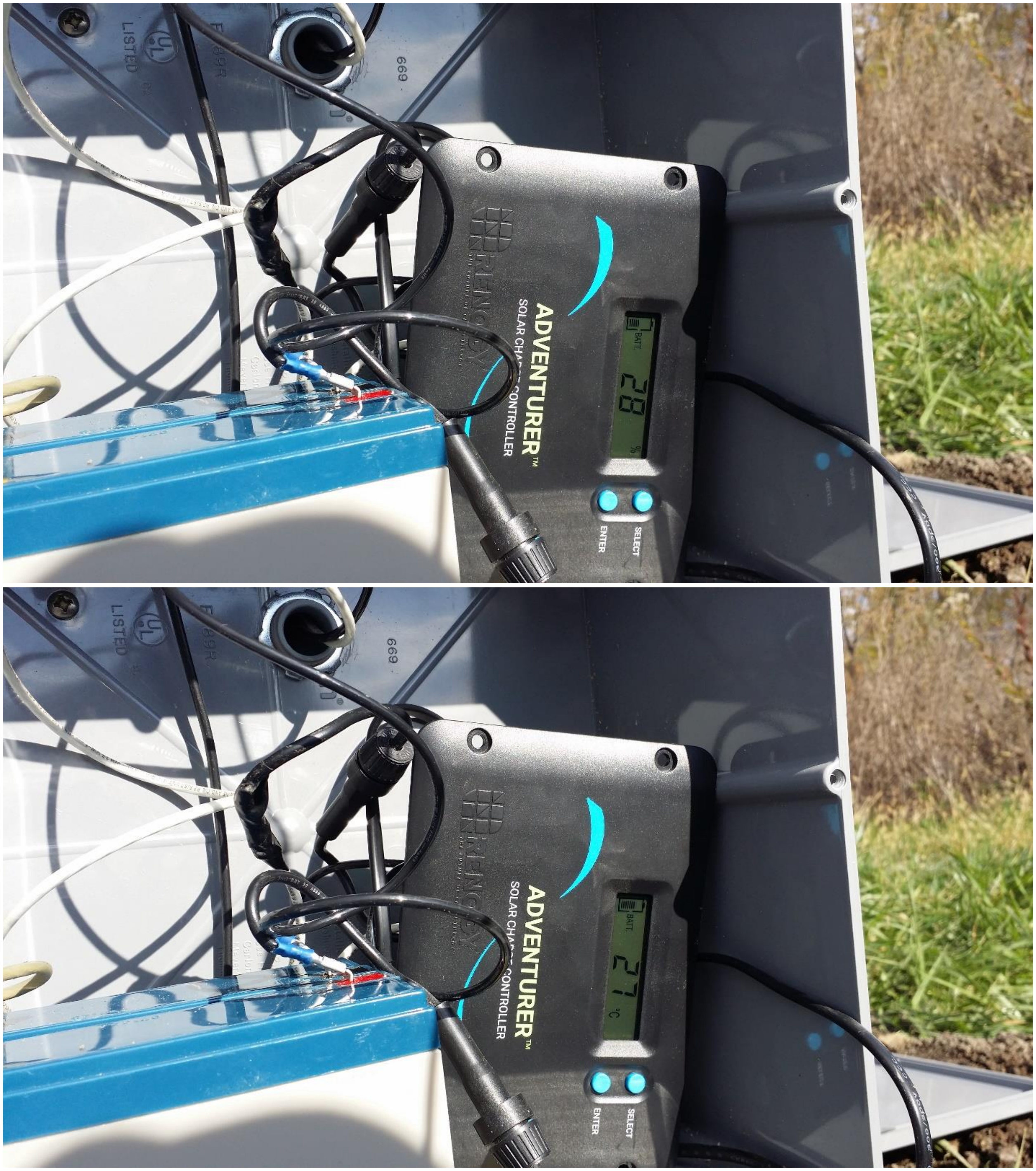


Main control box before adding any additional equipment. Wires for solar panel (red and black) and USB hub (white and black) are visible.

Charge controller being wired. The negative wires for both the USB hub and the battery packs are shown.

LCD display of solar charge controller after being connected to the batteries.

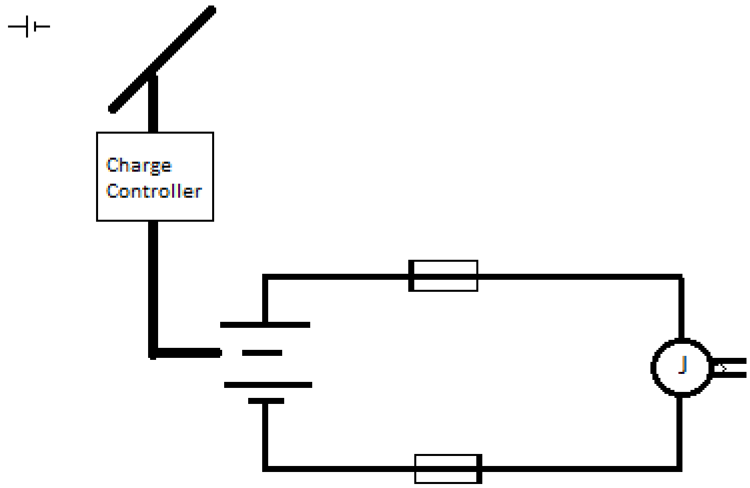


The charge controller is indicating that the batteries are currently charging. There is a battery symbol on the top/right side of the LCD display. These photos were taken as a burst and it is possible to see the battery level change between the two images.

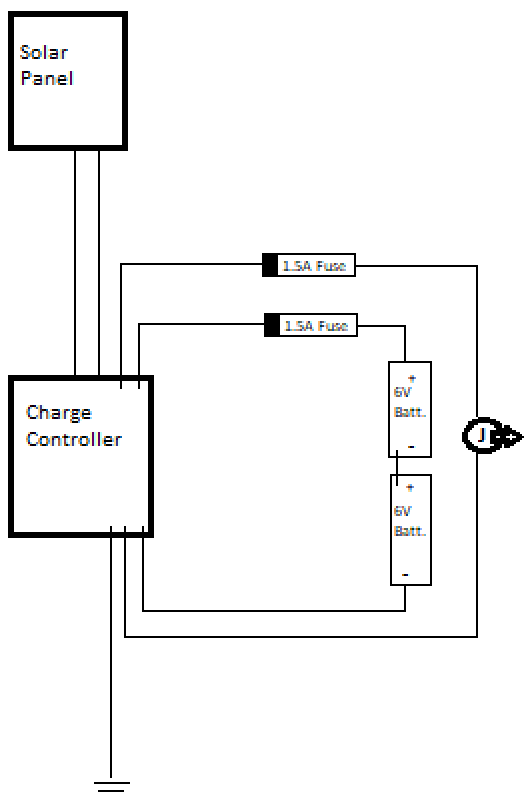
After completing reassembly, this was verification that the wiring was still working. You can see the cord going to the USB outlet while charging the device taking the photo.

Completed and operational system after clean up.

System from the parking area; visible in the background is the Car Doctors information kiosk.



Early diagram for the wiring.



Final wiring diagram.

Cost breakdown for the solar project.

Item	Cost before tax	number of units
Renogy Adventerer Charge Controller	$69.99	1
Coleman 6watt Solar Panel	$44.95	1
4"x4"X12' post	$15.40	1
12"x12"x6" control box	$34.61	1
Tow behind Post Hole Auger rental	$45.80	3 hr
50lb Bag of Fast Setting Cement	$16.41	3 @ $5.47
10' Stick of Grey PVC Conduit	$6.42	2 @ $2.59
Screws	$6.71	1 box
Pipe Straps	$3.40	1 bag
Cord Grips	$6.38	2 @ $3.19
PVC cement	$2.49	1 can
Wire Strippers	$3.99	1
4"x4" Post Connector	$4.98	1
White 12 AWG Wire 25'	$7.98	1 Spool
Black 12 AWG Wire 25'	$7.98	1 Spool
Green 12 AWG Wire 50'	$11.57	1 Spool
Glass Fuse Holder	$4.56	2
1.5A Glass Fuses	$1.94	1 box
1 Gang PVC box	$4.99	1
1 Gang PVC Weatherproof Cover	$4.99	1
IBEW Grounding and Electrical Permit	Unknown	
Total	$305.54	

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